Inductive proximity sensor and position transducer with a passive scale.

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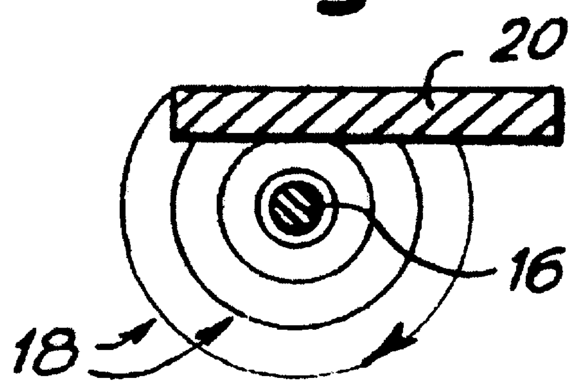
Abstract of **EP0455613**

An inductive proximity sensor, comprising a single length of sensor wire supplied at high frequency with an electronic supply circuit for this sensor wire, and means of detecting the greatest electrical losses and diminution of the sensor wire's inductance, as a result of the proximity of metal for the detection of said metal; as well as a measurement transducer - linear of rotary - consisting of a scale and a cursor, where the cursor is made up of at least one sensor wire and the scale is completely passive and made up of transversal short circuits at a constant step, for intercepting a part of the magnetic flux produced; the amount of flux intercepted being cyclically variable versus the relative position assumed during relative movements.

Fig. 4



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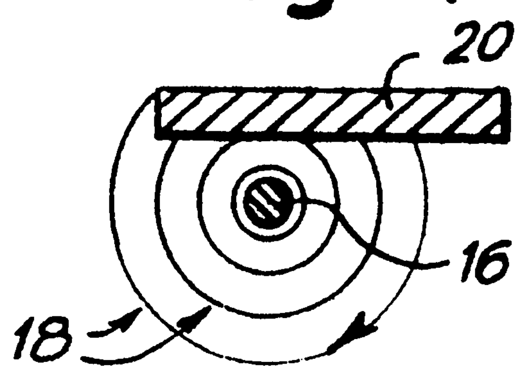
(54) Inductive proximity sensor and position transducer with a passive scale.

(57) An inductive proximity sensor, comprising a single length of sensor wire supplied at high frequency with an electronic supply circuit for this sensor wire, and means of detecting the greatest electrical losses and diminution of the sensor wire's inductance, as a result of the proximity of metal for the detection of said metal; as well as a measurement transducer - linear of rotary - consisting of a scale and a cursor, where the cursor is made up of at least one sensor wire and the scale is completely passive and made up of transversal short circuits at a constant step, for intercepting a part of the magnetic flux produced; the amount of flux intercepted being cyclically variable versus the relative position assumed during relative movements.

Fig. 4



engraved metallic mass, to form parallel and equidistant bar projections.

In an advantageous form of realization, the sensor wire is arranged in fret form, with components at a constant step and equal to the scale's step.

The transducer may include two frets placed on the cursor and out of phase by 180 mechanical degrees with respect to one step of the scale, in such a way that a sinusoidal signal is obtained from the difference of effect on these two frets. The transducer may include two pairs of frets out of phase with each other by 90 mechanical degrees with respect to one step of the scale which is considered to be 360 degrees; in this way two signals out of phase by 90 degrees (sine and cosine) are obtained from these two pairs. The four frets may be placed in the order 0, 90, 270, 180 degrees.

The transducer's scale may be made up of a grid with transversal and longitudinal short circuits, or obtained from solid metal bearing transversal engravings at a constant step.

To allow for zero resetting, a track is forseen that is parallel to and synchronized with the scale; the proximity sensor will also cooperate with this or these tracks. In practice two tracks may be forseen, one of which shows the continual presence and the other the continual absence of metal; these two orders are inverted in correspondence with the "zero" reference. On the zero resetting track codified engravings may be inserted which with a small shift allow for the reading of the absolute position.

Codification of information relative to the absolute position can be obtained with an unequivocal code, represented by a number of bit frames, in which a frame contains an unrepeatable configuration which makes up the synchronism.

The invention will be better understood following the description and the enclosed drawings, which shows a practicable exemplification which is not restrictive of the invention itself. In the drawing:

Fig. 1 shows traditional principle diagram;

Fig. 2 shows a diagram of a position transducer of indefinite length;

Fig. 3 shows a perspective diagram of the explanation in question;

Fig. 4 is the same diagram with the presence of a conductor in the magnetic flux;

Fig. 5 & 6 show possible diagrams of the supply circuits and respective voltage and current graphics;

Fig. 7 shows perspectively a realization diagram of the group including a step down transformer, whilst

Fig. 8 is a section diagram;

Fig. 9 shows a circuit with two sensors;

Fig. 10, 11 & 12 show a multiple turn scale in short circuit;

Fig. 13 is a variation with respect to Fig. 10;

Fig. 14 shows a scale engraved on a metallic block;

Fig. 15, 16 & 17 show executions with multiple sensors, and staggered groups;

Fig. 18 shows a modified arrangement with sensors staggered by 90°, for more precise measurements;

Fig. 19 shows a system for resetting from zero.

<u>Physical principle of the sensor</u>

If an electric coil 3 is supplied (Fig. 1) with alternate current from 5, in the surrounding space a magnetic field 7 is obtained with the same frequency of that of the supply current. In one turn in short circuit 9 immersed in this magnetic field induced currents are generated which give:

- losses of power (for Foucault currents)
- a diminution of the equivalent inductance of the supply circuit including the coil 3.

This principle is largely used in inductive proximity sensors, which in various ways exploit the "reflected" variations on the supply circuit for detecting the presence or not of metal.

It is possible to construct a position transducer of any length with a system such as in Fig. 2. The scale 12, which is completely passive, and made up of a sequence of solid metal 12A and void metal 12B at a constant step p; the cursor, made up of two proximity sensors 14A and 14B arranged at a distance of a 1/4 step (90 degrees), supplies, versus the position with respect to the scale, two signals V1 and V2,out of phase by 90 degrees; a bidirectional meter which receives the two signals counts the cycles and therefore supplies the position.

This system, if it uses normal proximity sensor techniques, can give measurement precision at the most in the order of 0.1mm, which is insufficient for many applications. The reason for this imprecision is the inability to "canalize" the magnetic flux produced into a fine and repeatable geometry.

If however the ferromagnetic nucleus is eliminated and the coil is reduced to a single length of wire 16 (Fig. 3) the magnetic flux lines generated 18 are strictly controlled by the geometry of the wire; what is more the magnetic induction is very strong in the immediate vicinity of the wire, becoming negligible at a distance of a few diameters.

If a metal conductor 20 passes near to the wire 16 (Fig. 4) a part of the magnetic flux 18 is intercepted; inside the metal induced currents are, generated in short circuit that, as in normal proximity sensors, dissipate energy and diminish the sensor wire's inductance.

The practical application of this priciple, which

An indispensable element in many automation systems is the precise control of movements: therefore position measurers are necessary (measuring devices or position transducers) that can be either linear or angular. Numerous types of transducers exist; those most used are:

Rotary types

1) Resolver or synchro: these are rotating transformers with one or more primary coils supplied by alternate current and at least two secondary coils which supply a voltage, which has the same primary frequency, and the amplitude of which is modulated by the variation of mutual induction. They exist in various constructive forms, including moltipolar types with high precision.
2) Rotary inductosyn: it is in effect a multipolar resolver with planar development, the coils of which, reduced to just one turn, are made up of frets printed onto a circuit board;
3) Rotary optical encoder: it is made up of a light sender, a modulated light grid reflected or transmitted versus the position, a number of photosensitive components which generate moderated electrical current and from which it is possible to measure the position.

Linear types

1) Linear inductosyn: it is identical to the rotary type, the only difference being that the frets are arranged in a straight line rather than on a circumference;
2) Optical bar: the principle is identical to the rotary optical encoder. The linear "scale" bears an imprinted reflecting bar at a constant step, whilst the cursor contains the light source and the references;
3) Magnetic scale: the linear "scale" is made up of a series of lines, as for the optical bar, but these are made up of small elementary magnets of alternate polarity North/South. The cursor bears the "magnetic reading heads" and the decodifying circuits.

Laser systems, which are far more precise than all the others listed, are normally applied only as reference instruments due to their high cost and the difficulty of applying them in an industrial environment.

The induction systems (resolver, synchro, inductosyn), which are amongst other things more difficult to apply because they require electrical connections to both parts in relative movement, are giving way to optical type systems, which have a good degree of precision and reasonable prices. However the insufficient reliability of an optical system is becoming more and more evident, above all in heavily automized plants, due both to dirt (oil, water, dust), which makes the reflecting components opaque, and to the scarce reliability of the light generators (bulbs or LED).

The subject of this invention is a special proximity sensor and its derivatives, inductive position transducers with a passive scale, which combine the precision and simplicity of assembly of the optical systems (which have a passive scale) with the robustness and reliability of induction systems (which are not very sensitive to dirt and do not have unreliable components).

According to the invention, an inductive proximity sensor is forseen, which comprises a single length of sensor wire of which the magnetic field is exploited, supplied at high frequency, an electronic supply circuit for this sensor wire, and means of detecting the greatest electrical losses and diminution of the sensor wire's inductance, as a result of the proximity of metal for the detection of said metal.

Two identical sensor wires may be forseen, arranged with differential outputs and facing a passive actuator which has such a geometrical form as to give the presence of metal in front of one sensor wire and the absence of metal in front of the other.

Advantageously one sensor wire may be supplied with square wave voltage at a high frequency. The square wave voltage may be achieved with two uncoupled condenser switches and the signal proportional to the losses is obtained from the circuit's supply current which generates the square wave voltage; alternatively the square wave voltage may be achieved with four switches arranged on a bridge, and the signal proportional to the losses is always obtained from the circuit's supply current which generates the square wave voltage.

A step down transformer may also be forseen with a high ratio of turns, interposed between the supply circuit and the sensor wire. The transformer may need only one secondary turn, which may be made up of one or more conductor strips tightly wound around the primary one.

A linear or rotary measuring transducer according to another object of the invention - consisting of a scale and a cursor - may have the cursor made up of at least one sensor wire and the scale is completely passive and made up of transversal short circuits at a constant step, for intercepting a part of the magnetic flux produced; the amount of the flux intercepted is cyclically variable versus relative position assumed during the relative movements.

The scale can be developed as a series of turns in short circuit, and may include further longitudinal short circuits for dividing the turns.

Alternatively the scale may be developed as an

in normal conditions supplies a negligible effect, is possible with a special geometry of the sensor wire, and with an adequate electronic supply circuit.

To maximise the effect it is necessary to:

- make sure that the current's passage in the sensor wire 16 is limited above all by the inductance of the wire itself (which changes in the presence of metal) more than by its own resistance (which remains fixed) and by the inductance and resistance of the supply circuit;
- dispose of a sensitive and precise supply circuit, which allows for the measurement of the minimum variation of losses produced by the nearness of metal.

However the presence of fixed losses is always noted (both in the sensor wire and the input) which, their fluctuation being due to variations in temperature, can diminish the precision of the measurement.

To achieve the cancellation of fixed losses, two sensor wires are available, supplied by identical circuits and used in differential. The passive actuator (namely the metal facing the sensor wire) must be realized in such a way that, if metal is present in front of one sensor wire, it is not present in front of the other and viceversa; the difference of the outputs of the two sensors cancels out the fixed losses and gives a precise result.

Electronic supply circuit.

The input frequency must be high (in the order of 1 megahertz or more) to maximise the useful inductive effect with respect to the ohmic resistance which masks the result: high frequency is also convenient because it allows for a simpler filtering of the alternating residual due to the input and therefore in conclusion a higher speed at which it is possible to make the detection.

The high frequency input of the transducer is not sinusoidal but square. A rudimentary circuit is shown in Fig.5. For a half-cycle switch 24 is closed and for a half-cycle switch 26 is closed. By means of a coupling condenser 28 the square voltage (value VL) generated is applied to the load L, which can be approximately considered to be made up of inductance and resistance in series. The load current IL at a steady state is therefore made up of a succession of exponentials which give an almost triangular state. The load current flows in the input in the half-cycle in which switch 24 is closed whilst it recycles on the load itself when switch 26 is closed. If there are no losses in the switches and the equivalent load resistance is zero, the average input current IA is zero; if however there are losses, both on the switches and on the load, the average input current is no longer zero: even without a detailed circuit analysis it is evident for the conservation of energy principle that the input power (average current IA for direct voltage E) is the same as the sum of all the power lost.

The average input current therefore makes up the usable signal in that, in the presence of metal facing the sensor wire, it increases both because of the greater losses directly provoked, and also because of the losses due to greater current being recalled by the diminution of inductance.

A possible variation of the supply circuit is indicated in Fig. 6: with an H shaped bridge connection the coupling condenser is eliminated. The functioning is substantially the same. Two pairs of switches 24A, 24B and 30A, 30B are symetrically arranged with respect to the branch in which the load L is inserted.

The switches in Fig. 5 and 6 can be MOS transistors, or, even simpler, a pair of switches can be made from a section of integrated circuit in CMOS fast technology (series 74HC..or 74AC..or similar) which contains a switch in the direction of input and one in the direction of earth.

It is not convenient to supply the sensor wire directly, at least with present electronic technology, because the losses on the switches become too high, to the point of masking losses on the load and the variations of inductance to be measured. So a step down transformer is interposed, that also has the merit of galvanically insulating the sensor wire, which is exposed externally and therefore may produce undesirable dispersions in the direction of earth. In Fig. 7 and 8 a transformer 34 is shown made up of a toroidal nucleus in ferrite 36, on which are wound the primary turns 38. The only secondary turn 40, which must present very low resistance and its own inductance, so as not to mask the useful effect, is made up of one or more copper strips exactly overlayed on the primary and soldered onto the printed circuit board 42.

43 indicates the passive scale, made up of solids and voids in the metallic mass.

On the same printed circuit board 42, which supports the transformer 34 and the electronic control circuit, but on the opposite face the sensor wire 44 is obtained. In order to minimize inductance and dispersed resistance of the secondary, every transformer is mounted immediately above the sensor wire 44, which is supplied by the metallized holes 46.

Two circuits are necessary to achieve the differential effect and therefore the cancellation of the fixed losses: a resulting simplified circuit is represented in Fig. 9.

In the general circuit there are two identical sections, each one consisting of: an integrated circuit Ic1 and Ic2, which contains the switches, com-

define the "zero".

Instead of engraving a single mark on the zero track, codified information can be engraved, always synchronized with the measurement scale, which allows, with a shift of a few steps, the absolute reading of the position.

The coding of solid/void on the zero track is done in an unequivocal way as described below.

The single information bits (obtainable from the presence or not of metal in correspondence with a step of the scale) are grouped in frames each of 'b' bit. An absolute position is codified in 'p' frames, of which the first is synchronism and is recognizable by its sole coding. The first bit of the data frames is always equal to '0', whilst the synchronism frame has all its bits (including the first) equal to '1'. Since every data frame contains "b-1" information bits (the first is not usable because it is always zero) and "p-1" frames for every available for every group, we have absolute information of (b-1)*(p-1) bit that is obtainable in b*p steps. The unequivocal range is therefore equal to:

b * p * 2 exp ((b-1)*(p-1)) steps.

For example if four frames of four bits are used, 9 bits (512 positions) of information are achieved with 4*4=16 steps. In the case of one step of the zero track coinciding with one step of the scale and it is 1mm, this makes an absolute measurement possible on 16*512=8192mm of the range: different numbers can be used if the range is insufficient.

If the value 1 is assigned to the presence of metal and 0 to the void, it is possible to have the following codification:

1111 0000 0000 0000 1111 0000 0000 0001 1111 0000 0000 0010 1111 0....

In general in a block of four frames there will be this configuration:

1111 0xxx 0xxx 0xxx... where x stands for a data (1 or 0) It will be easy for a system of downstream elaboration to recognize the sole synchronism sequence of the 5 bits '11110' and therefore reconstruct the absolute position.

In Fig.20 the configurations of scale 70 are shown, in black the hollowed out parts without metal, and the cursor 72 complete with codified tracks for zero resetting.

On scale 70 are:

- a track S21 which contains the succession of transversal short circuits at a constant step "p" to be used for the fine measurement;
- a track S11 which contains the codified information relative to the absolute position; the sequence of 1 and 0 is marked corresponding to the information bits;
- a track S31 which contains the codified information complementary to track S11.

On the cursor 72, which is seen from the side facing scale 70, the numbers n1 n2 n3 n4 are integers and indicate the distance of the four frets G11, G22, G33, G44, out of phase by 0, 90, 270, 180 degrees; the two sensors W11 and W22 for the codified tracks are also indicated, made up of a simple length of conductor.

The scales and cursors have until now been represented in linear form. In the case of rotary transducers, the configuration is identical, unless the longitudinal axis like the A-A of the measurement system has a circumferential development.

In the case of a circular transducer there are two practical configurations:

- in the first the scale and the cursor are arranged on a circle and therefore they are face to face;
- in the second the scale is traced onto a cylindrical surface (like the toothing of a stright-tooth gear) whilst the cursor, suitably bulged, is facing laterally.

It is understood that the drawing shows only an example given as a practical demonstration of the invention, since this invention can vary in shape and disposition without however changing the functioning principle. The presence of reference numbers in the claims enclosed aims to facilitate the reading of the claims with reference to the description and the drawing, and does not limit the scope of protection represented by the claims.

Claims

1. Inductive proximity sensor, characterized by the fact of including a single length of sensor wire (44,52, WME), of which the magnetic field is exploited, supplied at high frequency, an electronic supply circuit for this sensor wire, and means of detecting the greatest electrical losses and the diminution of the sensor wire's inductance, as a result of the proximity of metal for the detection of said metal.

2. Sensor as in claim 1, characterized by the fact that two identical sensor wires (14A, 14B) are arranged with differential outputs and are facing a passive activator (12) with geometrical form (12A,12B) such as to give the presence of metal in front of one wire and the absence of metal in front of the other.

3. Sensor as in claim 1 or 2, characterized by the fact that the sensor wire is supplied with square wave voltage at high frequency.

4. Sensor as in claim 3, characterized by the fact that the square wave voltage is obtained with two uncoupled condenser switches (9) and that the signal proportional to the losses is obtained

from the circuit's supply current which generates the square wave voltage.

5. Sensor as in claim 3, characterized by the fact that the square tension is achieved with four switches arranged on a bridge and that the signal proportional to the losses is obtained from the circuit's supply current which generates the square wave tension.

6. Sensor as in at least one of the previous claims, characterized by the fact that it includes a step down transformer (34; T1, T2) with a high rate of turns, interposed between the supply circuit and the sensor wire.

7. Sensor as in claim 6, characterized by the fact that the transformer includes a single secondary turn, and that this is made up of one or more conductor strips (40) tightly wound on the primary one (38).

8. A linear or rotary measurement transducer, consisting of a scale and a cursor, characterized by the fact that the cursor is made up of at least one sensor wire (16,44,52,WM1,WM2,60,G11,G22,G33,G44) and the scale is completely passive and made up of transversal short circuits (54, 56, 62, 66, 70) at a constant step, for intercepting a part of the magnetic flux produced; the amount of flux intercepted being cyclically variable as a function of the relative position assumed during the relative movements.

9. Transducer as in claim **8,** characterized by the fact that the scale is developed as a series of turns (54) in short circuit.

10. Transducer as in claims **8** and **9,** characterized by the fact that the scale can include further longitudinal short circuits (54A) for dividing the turns.

11. Transducer as in claim **8,** characterized by the fact that the scale is developed as an engraved metallic mass (54B,56,62) to form parallel and equidistant bar projections.

12. Transducer as in claim **8,** characterized by the fact that the sensor wire is arranged in fret form (WME;WM1,WM2;60;G11,G22,G33,G44) with components at a constant step and equal to the scale's step.

13. Transducer like that of at least claim **8,** characterized by the fact that it includes two frets (WM1,WM2) placed on the cursor and out of phase by 180 mechanical degrees with respect to a step of the scale, in such a way that a sinusoidal signal is obtained from the difference of effect on these two frets.

14. Transducer as in claims **8** and **13,** characterized by the fact that it includes two pairs of frets (60) out of phase by 90 mechanical degrees with respect to a step of the scale considered to be 360 degrees, in such a way that two signals out of phase by 90 degrees (sine and cosine) are obtained from these two pairs.

15. Transducer as in claim **14,** characterized by the fact that the four frets are placed in the order 0,90,270,180 degrees.

16. Transducer as in at least one of the claims from **8** onwards, characterized by the fact that the scale is made up of a grid (54, 54A) with transversal and longitudinal short circuits.

17. Transducer as in at least one of the claims from **8** onwards, characterized by the fact that the scale is derived from solid metal bearing transversal engravings at a constant step (43,54,56,62).

18. Transducer as in at least one of the claims from **8** onwards, characterized by the fact that at least one track is forseen (68 S11,S31), parallel and synchronized to the scale (66;S21), which allows for zero resetting, and that the proximity sensor cooperates with this or these tracks.

19. Transducer as in claim **18,** characterized by the fact that two tracks (68;69) show, one the continual presence and the other the continual absence of metal, the two orders being inverted in correspondence to the zero reference.

20. Transducer as in claim **18,** characterized by the fact that the zero starting track carries codified engravings which allow, with a small shift the reading of the absolute position.

21. Transducer as in claim **19,** characterized by the fact that the codification of the information relative to the absolute position is obtained with an unequivocal code, represented by a number of frames of bits, in which a frame contains an unrepeatable configuration which makes up the synchronism.

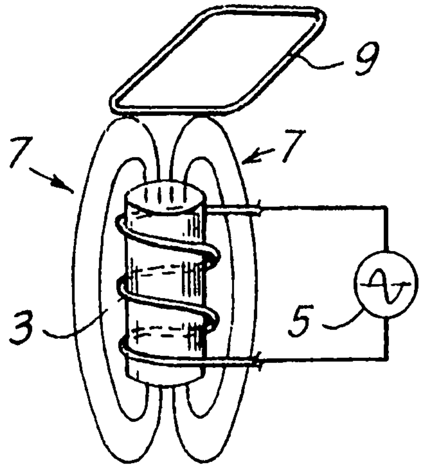


Fig. 1

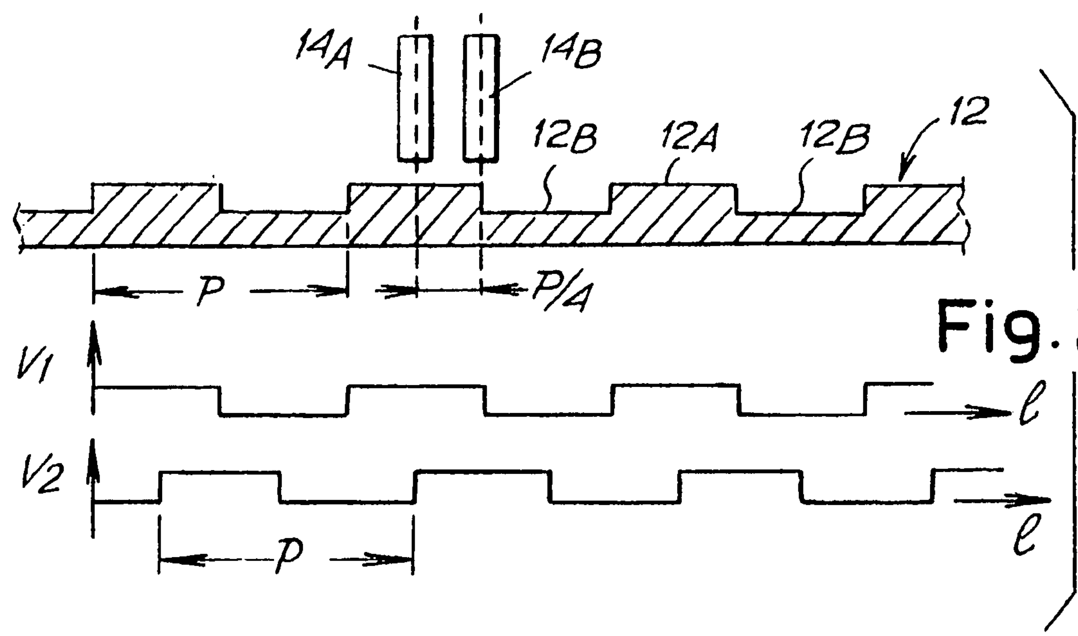


Fig. 2

Fig. 3

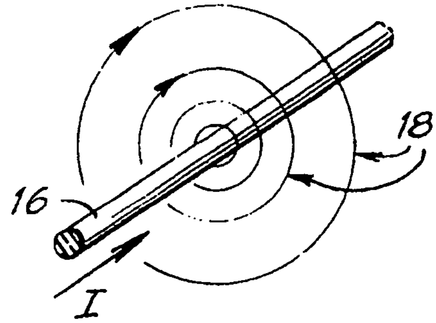


Fig. 4

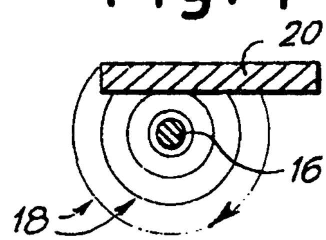


Fig. 5

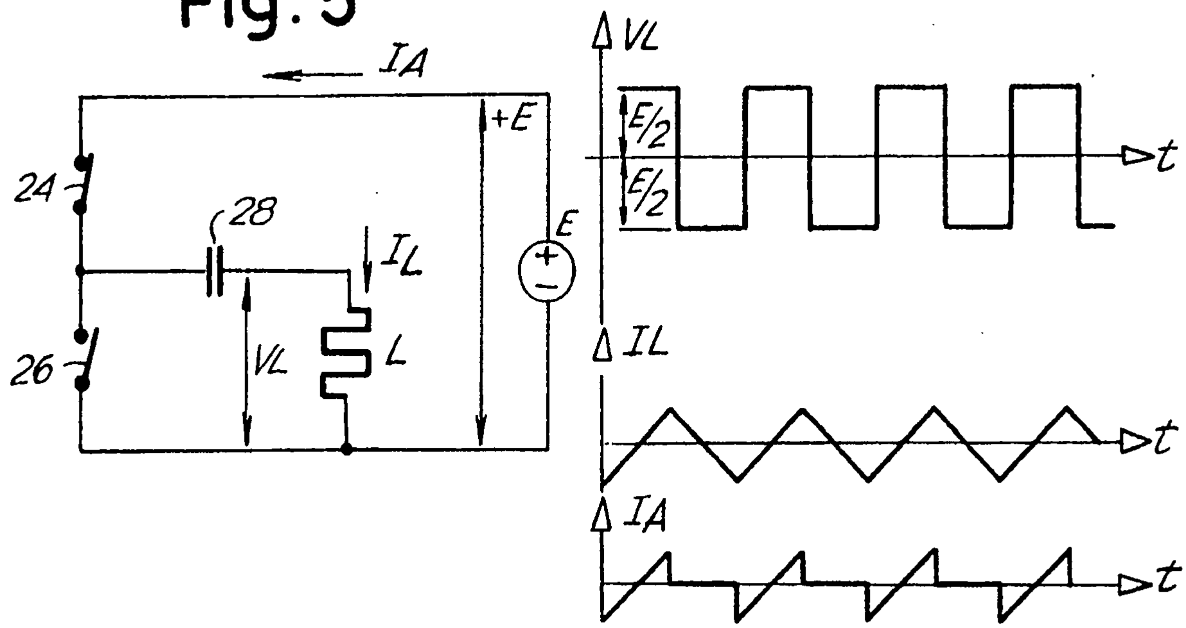

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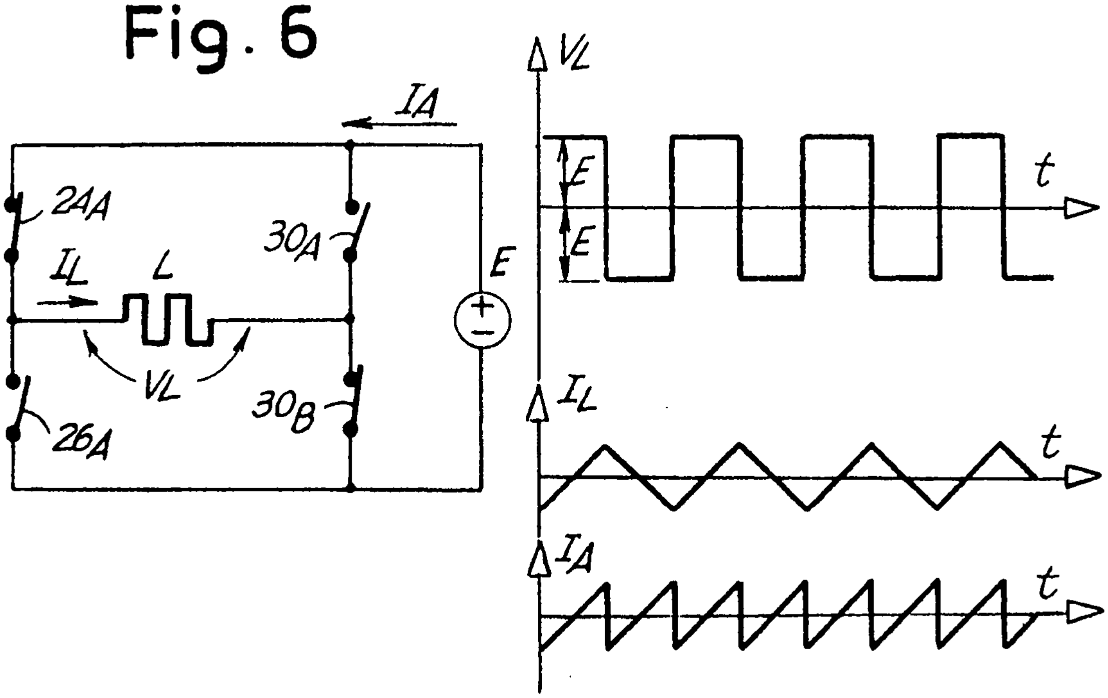
Fig. 6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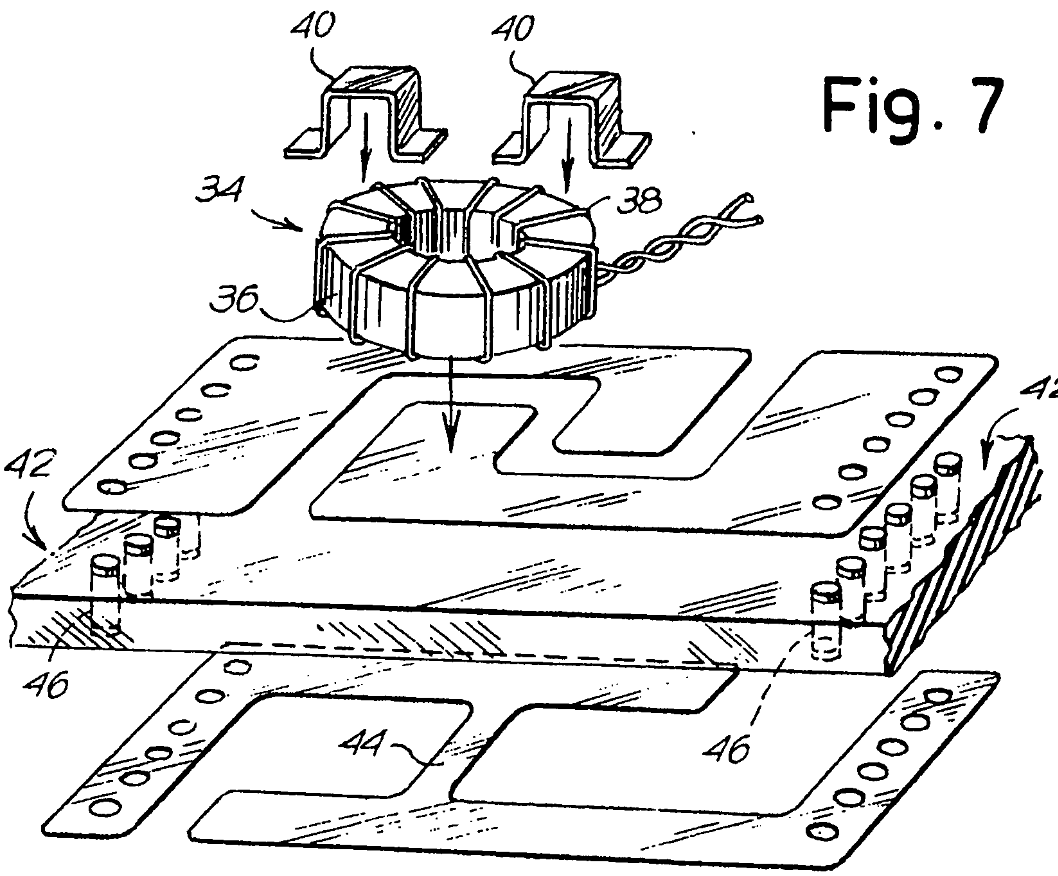


Fig. 7

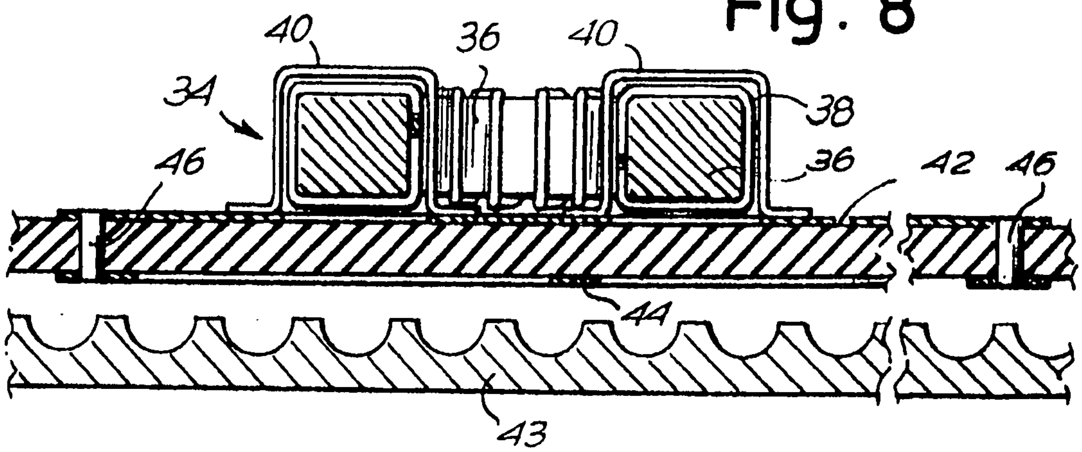


Fig. 8

Fig.9

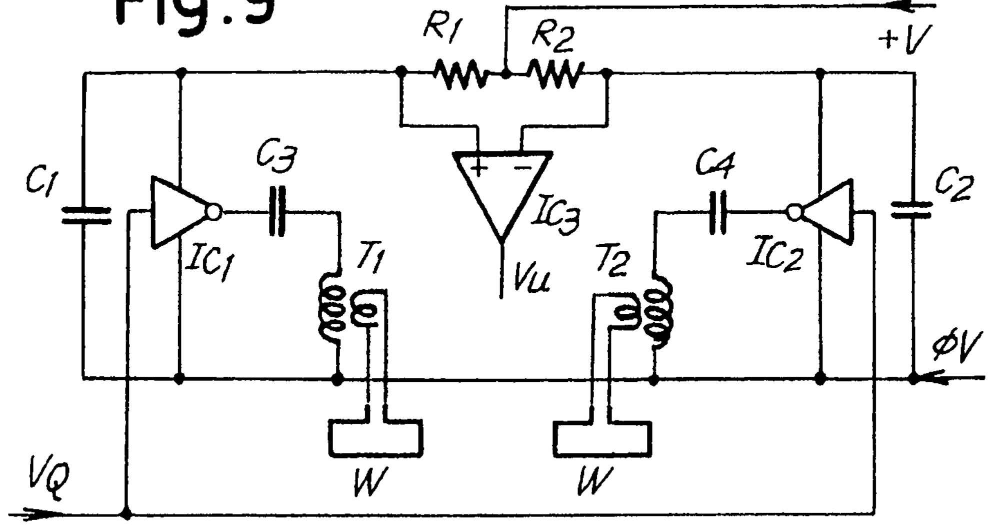
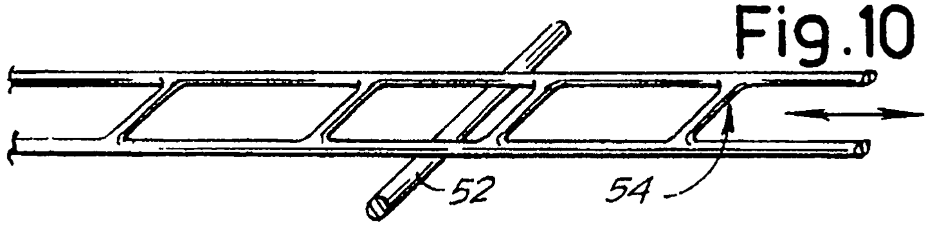


Fig.10



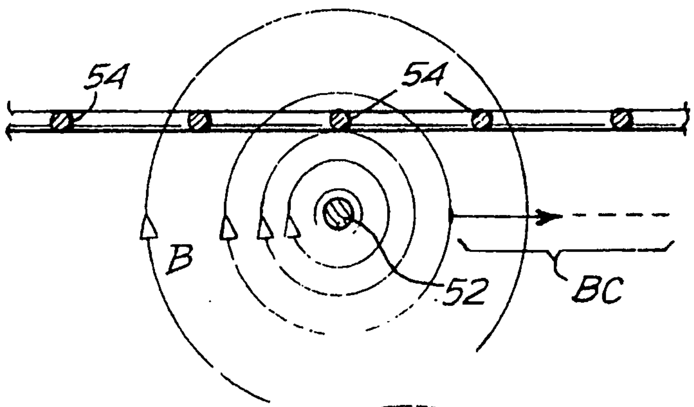


Fig.11

Fig.12

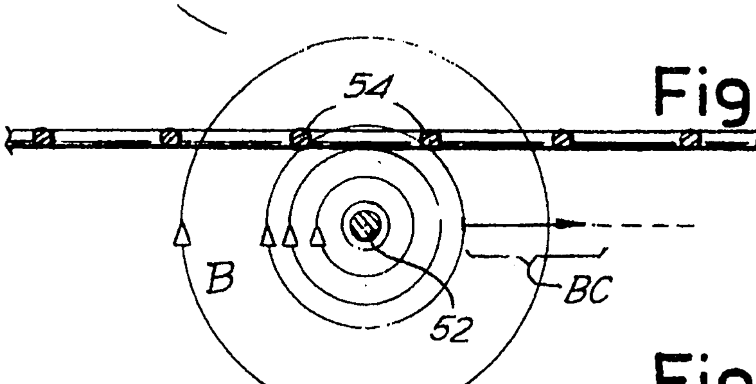


Fig.13

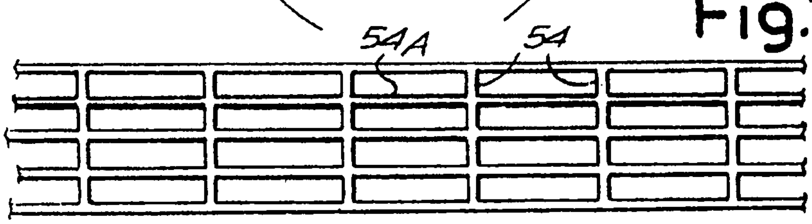
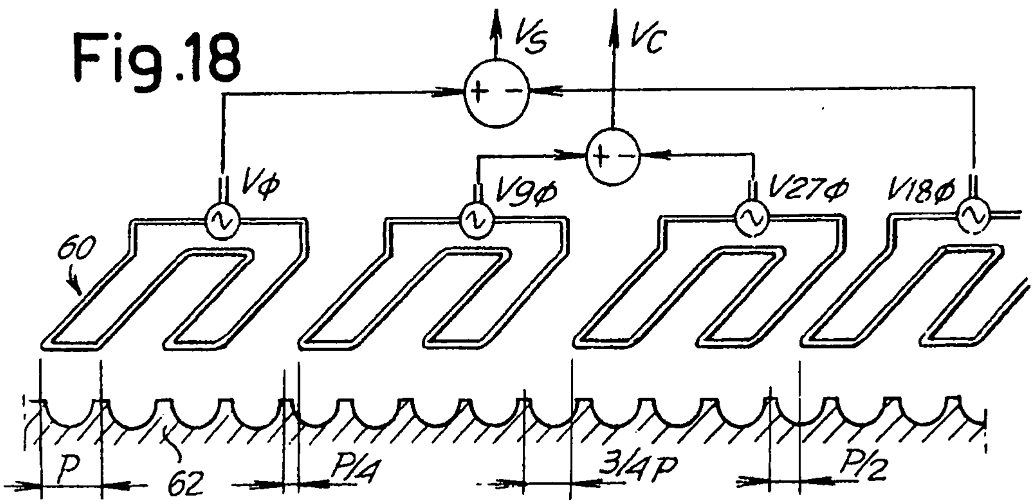


Fig.18



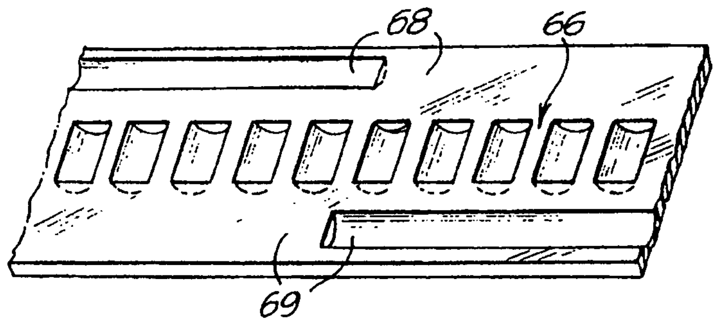


Fig.19

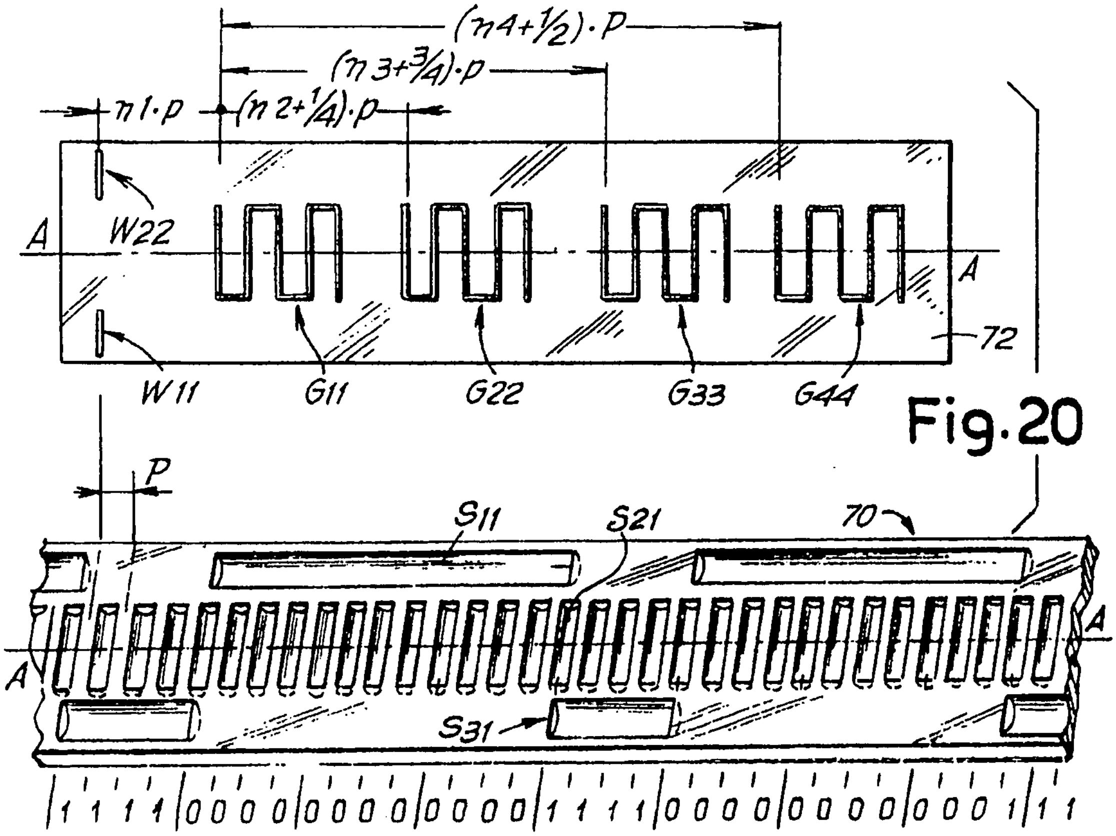


Fig.20